References

NOISE IN TRANSISTOR MIXERS AT HIGH FREQUENCIES

In his paper,[A] R. G. Meyer has made the following statements concerning our paper on noise in transistor mixers.[B]

(*a*) 'It will be shown in this paper that the ordinary transconductance of the transistor at some low frequency (the intermediate frequency) is not independent of the presence of a high-frequency local-oscillator (l.o.) voltage as assumed by Vogel and Strutt. This factor arises in the consideration of noise at the intermediate frequency (i.f.) owing to the transistor-base resistance, and is a significant term in the noise-figure expression.'

(*b*) 'It has been shown that the mixer input impedance (which again directly affects the noise figure) is not equal to the equivalent amplifier input impedance, as implicitly assumed by Vogel and Strutt, but may differ from it by a factor of 2 or more.'

(*c*) 'It has been shown that the conversion transconductance (which directly affects the noise figure) of transistor mixers at high frequencies cannot be predicted by the simple means employed by Vogel and Strutt.'

Statement (*a*) has previously been made in another paper by R. G. Meyer.[C]

Mr. Meyer's mixer circuit, namely Fig. 1 in Reference A, is essentially different from the circuit considered in our paper (Fig. 3). Therefore, no one could expect his results to coincide completely with ours. The fact that this basic difference is not even mentioned by Mr. Meyer tends to give his references to our paper a most superficial character. None of his adverse statements is supported by proof. Furthermore, Mr. Meyer must have overlooked the following facts, which contradict his statements quoted above:

(i) Statement (*a*) is wrong, as we have nowhere assumed independence of the oscillator voltage.

(ii) Nowhere in our paper on mixing processes at high frequencies do we use explicitly an input impedance in our computations. We do not work with a set of constant parameters at a fixed operating point, because, in mixer stages, the actual operating point is varied periodically by the oscillator signal. The influence of the oscillator voltage upon the transfer processes is considered by working with the dynamic transfer characteristic. The input impedance mentioned by Mr. Meyer figures implicitly in our computations, as is evident from our paper.

(iii) As for the very general and unproved statement (*c*), our measurements showed an excellent agreement with the computations. Of course, the restrictions due to the approximation method and the size of the oscillator voltage outlined in our paper have to be taken into consideration. Furthermore, the equation for the noise factor contains, as a special case, the noise formula for low frequencies obtained by R. R. Webster[D] (Reference 1 of Mr. Meyer's paper). This constitutes another proof of the validity of our computation.

19th August 1968

J. S. VOGEL

IBM Extension Suisse
Zurich, Switzerland

M. J. O. STRUTT

Professor and Director
Department of Advanced Electrical Engineering
Swiss Federal Institute of Technology
35 Gloriastreet
8006 Zurich, Switzerland

Vogel and Strutt have raised a number of points with respect to my paper.[A]

Their first comment is that the mixer circuit (Fig. 1 of Reference A) considered in my paper is essentially different from their circuit (Fig. 3 of Reference B). If these two circuits are examined, it will be seen that there are two apparent differences. However, for the reasons given below, the small signal analysis of the two circuits will be identical:

The first apparent difference is that the l.o. voltage in my circuit is assumed to be in the base lead, whereas in their paper the l.o. is placed in the common emitter lead. Since we both assume ideal tuned circuits (i.e. a short circuit at all frequencies but their centre frequency), the two configurations are identical, and, in both, the signal and l.o. voltages appear in series across the emitter–base junction.

The other apparent difference between the two circuits is that my circuit has a stabilised d.c. operating point (the usual mixer configuration), whereas their circuit is an unstabilised mixer stage. For the former, a fixed average (d.c.) collector current is obtained for any l.o. voltage applied, whereas in the latter circuit the average collector current depends on the l.o. voltage. However, for given average collector currents and given l.o. voltages, the small-signal analysis of both circuits must again be identical. The bypass capacitors in my circuit become short circuits at signal frequencies.

With respect to the three explicit points raised by them:

(*a*) This point refers to the amplification of the base-resistance thermal noise at the intermediate frequency (i.f.). This noise contribution is considered on p. 343 of their paper,[B] where they state:

> 'The first term of the base noise voltage in expr. 23, $E_{bb'm} \cos(\omega_z t + \phi_A)$, is simply amplified. The only influence of the oscillator voltage is to increase the value of direct current; and one has to consider I_{CT} instead of I_{OC}.' (The term $E_{bb'm} \cos(\omega_z t + \phi_A)$ represents base resistance noise at the intermediate frequency.)

Now it is shown on pp. 488–489 of my paper[A] that, while the above result is true for low frequencies, it is definitely not true for high-frequency local-oscillator voltages. Fig. 3 of my paper shows the theoretical results, while Figs. 5 and 6 are representative samples of a large number of measurements which verify these results. Fig. 3 shows clearly that, for a given average collector current, the i.f. transconductance is unaffected by the presence of a low-frequency (factor B as defined in Reference A, is small) l.o. voltage. However, in the presence of a high frequency (factor B approaching 1) l.o. signal, the i.f. transconductance may be as small as 0·2 of the previous value.

(*b*) This point concerns the effective input impedance of the mixer at the signal frequency. As stated by the authors, they do not consider explicitly the input impedance of the mixer. However, their approximate analysis of the nonlinear differential equation of the transistor yields eqn. 10 in their paper for the mixer transfer function. Examination of their eqn. 10, and, in particular, the terms $1/(1 + q_2)$ and $1/\sqrt{(1 + \tau_2^2)}$, shows that implicit in this equation is the assumption that the mixer input impedance at high frequencies is equal to the equivalent amplifier input impedance. As shown on p. 488 of my paper[A] (and in more detail in Reference C) this result is true at low frequencies only. Exact solution of the transistor nonlinear differential equations in Reference C shows that, at high frequencies, the mixer input impedance may be twice the equivalent amplifier input impedance. These results have been verified by a large number of measurements, samples of which are given in Fig. 14 of Reference A and Fig. 2 of Reference A.

(*c*) This concerns the high-frequency conversion transconductance of the mixer. Eqn. 10 of their paper gives an expression for conversion transconductance. This was obtained from an approximate solution of the transistor nonlinear d.e. and shows the conversion transconductance to be directly proportional to I_{Clm}, the peak value of the collector-current component at the l.o. frequency. As can be seen from Fig. 7 of Reference C, this result is true at low frequencies only (frequency factor B approaching zero). At higher frequencies, Fig. 7 predicts that increasing local-oscillator voltage (which causes increasing I_{Clm}) above about 50 mV actually causes a fall in conversion transconductance. (Figs. 8 and 9 of Reference C are part of an extensive series of measurements verifying these results.) The above effect is not predicted by eqn. 10 of Reference B.

Finally, the authors state that their measurements showed excellent agreement with the computations. This they owe to two factors. The first (and most important) is the very low oscillator voltage (typically 20 mV r.m.s.) used for their measurements. The various deficiencies in their theory, described above, all become less pronounced as the l.o. voltage is reduced. High-frequency mixers in practice have typically 100 mV or more of l.o. voltage for minimum noise figure (see Fig. 18 of Reference A). Under these conditions, the theory of Reference B would be grossly in error.

The second factor to be considered here is the relatively low frequency at which the measurements were performed. As pointed out in the above discussion, the various assumptions made in their paper (which are not valid at high frequencies) are all valid at low frequencies, i.e. where reactive effects may be neglected. Most of the measurements described in their paper were performed at an oscillator frequency of 1 MHz on an OC45 transistor. Substituting typical parameters for this transistor gives a frequency factor B of 0·3 or less at 1 MHz. This combination of very low oscillator voltage and relatively low frequency prevented the detection of the errors in their theory.

R. G. MEYER

Department of Electrical Engineering
University of Melbourne
Parkville N2, Vict., Australia

References

A MEYER, R. G.: 'Noise in transistor mixers at high frequencies', *Proc. IEE*, 1968, **115**, (4), pp. 487–495

B VOGEL, J. S., and STRUTT, M. J. O.: 'Noise in transistor mixers', *Proc. Inst. Elect. Electron. Engrs.*, 1963, **51**, pp. 340–349

C MEYER, R. G.: 'Signal processes in transistor mixer circuits at high frequencies', *Proc. IEE*, 1967, **114**, (11), pp. 1605–1612

D WEBSTER, R. R.: 'The noise figure of transistor convertors', *IRE Trans.*, 1961, **BTR-7**, pp. 50–65